STATUS OF INSECTS INTRODUCED INTO HAWAI'I FOR THE BIOLOGICAL CONTROL OF THE WILD BLACKBERRY RUBUS ARGUTUS LINK

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INTRODUCTION

The wild blackberry Rubus argutus Link (previously identified in Hawai'i as R. penetrans Neal 1965, Haselwood et al. 1983 and listed as R. lucidus by the State Department of Agriculture) is believed to have been introduced into the Islands from the continental United States in 1894, probably for its desirable fruit (Neal 1965). Its potential pest status was recognized as early as 1929 (Pope 1929). Today, it is well established as a major weed in disturbed forests, pastures, and roadsides on approximately 16,188 ha between 914 m to 1700 m on the islands of Hawai'i, Maui, and Kaua'i (Neal 1965, Davis 1970). Its thick impenetrable stands and rapid rate of spread caused the State Department of Agriculture to designate it as a "noxious" weed in 1963 (Gardner and Davis 1982).

Between 1963 and 1969, the State Department of Agriculture introduced and released five species of insects to control R. argutus. The historical data of these introduced insects are presented in Table I. Three species became established by the mid-sixties and in some areas were causing extensive foliar damage (Davis and Krauss 1966). The leaf skeletonizer Schreckensteinia festaliella Hubner and the leaf-roller Croesia zimmermani Clarke were very active on Maui and on Kaua'i during 1965 and 1966, and had extended their range enough so that the blackberry was considered to be under "partial" control (Davis and Krauss 1967). The third established species, the blackberry sawfly Priophorus morio Lepeletier, was recovered in 1967 and 1974 in low numbers (Nakao 1967, Davis 1974). The crown and stem borer Bembecia marginata Harris and the foliar feeding beetle Chalamisus gibosa Fab. were also released in 1963 and 1969, but were not recovered (Davis 1970).

Since then, no comprehensive studies were conducted to evaluate insect introductions on blackberry. Although the early efforts of biological control of R. argutus showed promise, it was generally concluded that this attempt was inadequate. Stands of R. argutus are reported to be growing vigorously in some localities and because of its ability to spread rapidly in Hawaiian forests, where it displaces native

Table I. Insects introduced into Hawai'i for biological control of wild blackberry (Rubus argutus).

Species	Source (Year imported)	Date released	Release site	Status	Reference
Schreckensteinia festaliella Hubner (Lep.: Heliodinidae)	Calif. 1963	Oct. 1963	Olinda, Maui	Established	Davis & Krauss 1964, 1965, 1966, 1967
		Nov. 1963	Kokee, Kaua'i	Established	Davis & Chong 1969
		Aug. 1966	Kahuku Ranch, Hawai'i	Established	Davis 1970
Croesia zimmermani, Clarke formerly Apotoforma sp. (Lep.: Tortricidae)	Mexico 1963	Aug. 1964	Olinda, Maui	Established	Davis & Krauss 1965, 1966, 1967
		July 1966	Kokee, Kaua'i	Established	Davis & Chong 1969
		Aug. 1966	Kahuku Ranch, Hawai'i	Established	Davis 1970
Bembecia marginata, Harris (Lep.: Aegeriidae)	Oregon 1963	Aug. 1963	Olinda, Maui	Not established	Davis & Krauss 1964, 1967
		Sept. 1963	Kokee, Kaua'i	Not established	
		Aug. 1966	Mt. Kaala, O'ahu	Not established	Nakao 1967
			Waiakamoi, Maui		
Priophorus morio, Lepeletier (Hym.: Tenthredinidae)	Oregon	June 1966	Olinda, Maui	Established	Davis & Krauss 1967
	Calif.		Waiakamoi, Maui		Nakao 1967
	Washington	June 1966	Mt. Kaala, O'ahu	Not established	Davis & Chong 1969
	1966	July 1968	Wright Rd. Vol., Hawai'i	Established	Davis 1976, 1979
Chalamisus gibosa, Fab. (Col.: Chrysomelidae)	Missouri 1969	May 1969	Mt. Kaala, O'ahu	Not established	Davis (1970)

plant species (Haselwood et al. 1983), it has been added to the list of exotic plants for which better control is desired in the National Parks of Hawai'i (Gardner and Davis 1982, Smith 1984).

It is recognized by Resource Manager's in Hawaii, that the establishment of an effective biological control program is the most feasible, long-range method of controlling this weed. However, before undertaking a new program of introducing new species of insects for R. argutus, a full evaluation on the status of earlier introductions was needed.

METHOD

During 1984 and 1985, a field survey was conducted of blackberry infestations on the islands of Hawai'i, Maui, O'ahu, Moloka'i, and Kaua'i. Permanent sites were set up on Hawai'i, Maui, and Kaua'i for intense sampling. These sites were checked bimonthly to determine if seasonal trends in abundance and species composition occurred. Twelve permanent sites were selected: on Hawai'i, three sites along the Mauna Loa Strip Road and two sites at Palani Ranch on the slopes of Mt. Hualalai; on Maui, three sites in the Makawao Forest Reserve; and on Kaua'i, four sites located in the Puu Ka Pele and Kokee areas. Other blackberry locations, such as Laupahoehoe, Keanakolu and Power Line Road on the island of Hawai'i, were sampled periodically and included in the final data.

At each site, a sample of 25 randomly selected cane tips, each 50 cm long were collected. Each cane tip was individually examined and insects were tallied. Larvae found were placed into petri plates to complete their development and be reared to adults. Parasites emerging from infected larvae were collected and identified. Larval mortality attributed to diseases was also monitored and tallied by petri plate rearing. Additionally, 5 cane tips randomly selected from the sample was enclosed in a perforated plastic sack, placed in water, held in the lab for 2 weeks, then reexamined. This allowed eggs to hatch and small larvae to grow large enough to be visible and be included in the tally.

RESULTS

The results of the survey with regard to the presence and abundance of insects found with R. argutus are presented in Table II. The leaf skeletonizer Schreckensteinia festaliella Hubner was the most frequently encountered of the introduced Rubus insects, with a relative abundance of 51.53%. This small microlepidopteran, measuring only 5 mm in wing span, is widely dispersed in the United States and in Europe. It was introduced from California and released at Olinda, Maui, and Kokee,

Table II. Summary of insects collected on Rubus argutus and its relative abundance.

Species	Total samples (25 canes each)	Total samples w/ insects	Relative abundance Pct[1/]	Sample Range	Sample Ave. $\bar{x}$ (SE)	Insects per shoot
S. festaliella Hubner	82	69	51.53	0 - 873	58.70 (12.79)	2.35
C. zimmermani Clarke	82	76	38.05	0 - 234	43.34 (5.47)	1.73
A. emigratella Busck	82	67	8.16	0 - 71	9.29 (1.26)	0.37
P. morio Lepeletier	82	9	1.00	0 - 30	1.13 (0.50)	0.045
S. sp. nr. paludicola Butler	82	21	0.49	0 - 5	0.56 (0.44)	0.022
Unknown Lepidoptera[2/]	82	21	0.77	0 - 15	0.88 (0.25)	0.035

[1/]Percent of total insects found.

[2/]Identified as: Oeobia pyranthes Meyrick (endemic)
Hyposmocoma sp. (endemic)
Epiphyas postuittana Walker (immigrant)

Kaua'i, in 1963 (Davis and Krauss 1964), and on Hawai'i in 1966 (Davis and Krauss 1967). By 1969, the State Department of Agriculture reported S. festaliella established at their released sites and expanding in range (Davis and Krauss 1965, 1966, 1967; Davis and Chong 1969; Davis 1970). S. festaliella occurred in 84.15% of our samples, with high populations found on Hawai'i and Kaua'i. Sampled populations ranged from 0 to 873 individuals at the Mauna Loa site (1195 m elev.). Averaging 2.35 larvae per shoot or 58.70 larvae per sample, this indicated a substantial wild population utilizing blackberry. Several larvae may occupy a single leaf, so damage is noticeable when high populations exist.

The leaf roller Croesia zimmermani Clarke was originally identified as Apotoforma sp. in earlier Hawaiian literature (Zimmerman 1978). This small, brown moth was introduced from Mexico in 1963 and liberated at Olinda, Maui, in 1964; Kokee, Kaua'i, and Kahuku Ranch, Hawai'i, in 1966 (Davis and Krauss 1965, 1966, 1967) (Table I). In our survey, C. zimmermani is second to S. festaliella in abundance (38.05%), but is the most widely dispersed of the introduced Rubus insects, with 92.68% occurring in samples from Hawai'i, Maui and Kaua'i. C. zimmermani ranged from 0 to 234 individuals per sample which was also recorded at the Mauna Loa site. Averaging 1.73 larvae per shoot or 43.34 larvae per sample, they caused much of the Rubus feeding damage that we have observed (Table II). Larvae are often found in young Rubus leaves at the tips of actively growing shoots that they stitch together to form a protective shelter to feed inside. During larval development, several leaves are attacked and fed upon in this manner. Feeding damage by C. zimmermani is the most prevalent of the introduced Rubus insects seen and was observed causing extensive foliar damage on blackberry in some areas.

The third most abundant insect (relative abundance of 8.16%) encountered in our survey is not one of the Rubus insects introduced for biological control but an immigrant, the Mexican leaf-roller Amorbia emigratella Busck. Occurring in 81.71% of our samples and averaging 0.37 larvae per shoot or 9.29 per sample, A. emigratella is as widely distributed as S. festaliella. Ranging up to 71 larvae per sample, its impact on blackberry can be damaging (Table II).

A. emigratella was first discovered in Honolulu, O'ahu, in 1902 by Dr. R.C.L. Perkins who found it to be common on orange trees. This general feeder not only attacks Rubus plants but koa, peanut, papaya, gardenia, cotton, sweet potato, tomato, macadamia, and Passiflora (Zimmerman 1978). We found A. emigratella present on blackberry on all islands surveyed except Moloka'i. Due to its relatively large size (25 mm last instar larvae), A. emigratella is capable of consuming large amounts of Rubus leaves.

The defoliating sawfly Priophorus morio Lepeletier was introduced from Oregon, California, and Washington in 1966 and released on Maui and O'ahu in the same year (Davis and Krauss 1967). A second shipment from California was released at Volcano, Hawai'i, in 1968 (Davis 1976). A single larva was recovered from Maui in 1967 (Nakao 1967) and none from O'ahu. On Hawai'i, P. morio was not recovered until six years after the initial release in 1974 (Davis 1976) (Table I). Since then it was reported well established in Hawai'i Volcanoes National Park, particularly in Kipuka Puaulu and the Mauna Loa Strip Road (Davis 1976). During this survey, we have located numerous populations of this sawfly. It is established in the Makawao Forest Reserve on Maui and at the Laupahoehoe and Hualalai areas on the island of Hawai'i but always in low numbers. Infrequently encountered (1.00% of all defoliators found), P. morio has not experienced the high population outbreaks of S. festaliella and C. zimmermani. Averaging .045 larvae per shoot or 1.13 larvae per sample, P. morio does not seem to be stressing R. argutus (Table II).

During the course of our survey, we found 5 additional species of lepidoptera associated with R. argutus. Three of these were collectively grouped and labelled as "unknown lepidoptera" at the time of collection. But since then, they have been identified as the endemic Oeobia pyranthes (Meyrick), the endemic Hyposmocoma sp., and the immigrant Epiphyas postvittana (Walker). Together, the 3 species occurred in 25.61% of our samples, or .035 larvae per shoot. Two other species of lepidopteras, the endemic geometrid Scotorythra sp. nr. paludicola (Butler) and the introduced noctuid Peridroma saucia (Hubner), were occasionally sampled. S. sp. nr. paludicola occurred in 25.61% of our samples with 0.22 larvae per shoot and is included in the final tally (Table II). Due to the infrequent occurrence of these 5 species of lepidoptera, we felt that they were not effective in controlling blackberry.

The Fuller rose beetle Pantomorus cervinus Boheman was frequently observed on R. argutus and damage by this beetle was usually confined to low-lying, grass covered portions of blackberry plants. Typical feeding damage by the rose beetle resulted in chewed out leaf margins often resembling a jagged saw edge. No data were taken on this beetle other than its occurrence on all islands surveyed. Other phytophagous insects found on R. argutus included aphids, leaf hoppers, mealybugs, and thrips.

ENVIRONMENTAL FACTORS

We found high populations of S. festaliella and C. zimmermani during certain times of the year, usually during peak flushing of the Rubus plant. Followup sampling show that these high populations are almost always followed by sharp decreases. In order to explain the rubus insect's failure to sustain high population levels needed for good

control of this weed, we have attempted to identify the environmental factors that may influence this phenomenon. Environmental factors considered were food, seasonal differences, predators, parasites, and diseases:

Food. Food shortages, even during periods of reduced plant growth, are nonexistant. R. argutus does not have a dormancy period where foliar growth is unavailable. Although foliar growth may be reduced, some foliage remains on the plant where it can be utilized by the Rubus insects.

Seasonal differences. We have observed Rubus insects at all life stages during the year and conclude that no hibernation or aestivation period affects population levels. They seem to be active year-round. We found no indication that local weather influences variation in the populations. However, altitudinal differences may seem to restrict the population at higher altitudes, since at one of our highest sampling sites, 1676 m elev., populations were consistently lower.

Predators. Other than an occasional spider found in our survey, no large predatory groups, such as ants, were consistently found associated with R. argutus. However, several predatory insects, including nabids, chrysopids, and a predatory geometrid were collected. Although infrequently observed, it should not be discounted that predation, particularly of the early instars, may have some impact on the population levels of introduced insects. Interestingly, the nabids and geometrid are endemic but have learned to utilize a foreign host as food.

Parasites. The seven species of hymenopteran parasites associated with R. argutus in our survey are presented in Table III. Pristomerus hawaiiensis Perkins was the most frequently encountered parasite associated with S. festaliella. Eight adult P. hawaiiensis emerged fron 1339 larvae of S. festaliella, for a .60% occurrence. Total parasitism by all 7 species (Table IV) amounted to only 0.39% of the Rubus insects reared in the lab. Parasitism on larger larvae was concluded to have a very minor effect on the introduced Rubus insects. Study limitations prevented us from sampling the microfauna of immature insects associated with blackberry. However, we have recently discovered evidence of parasitism by an unidentified hymenoptera on the eggs of C. zimmermani, which suggests that parasites may be playing a more significant role in curtailing high populations necessary for good biological control of blackberry.

Diseases. Larval mortality was high when using the petri plate technique. Table IV lists the mortality factors suffered by the laboratory reared insects associated with R. argutus. While some

Table III. Parasitic hymenoptera associated with Rubus argutus insects.

Hymenoptera	Host
Ichneumonidae: Pristomerus hawaiiensis Perkins	S. festaliella Hubner
Braconidae: Meteorus sp. nr. ictericus Nees	A. emigratella Busck
Ichneumonidae: Trathala flavoorbitalis	C. zimmermami Clarke
Braconidae: Cotesia sp.	
Ichneumonidae: Diadegma blackburni Cameron	Unknown Lep.
Ichneumonidae: Coccygomimus punicipes Cresson[1/]	
Scelionidae: Opisthacantha sp.[1/]	

[1/]May not prey upon the Lepidopterous insects associated with R. argutus. They were collected on R. argutus and not through petri plate rearing.

Table IV. Mortality factors affecting the insects of Rubus argutus encountered during 1984-1985 survey.

Species	Found	Reared	Successful	Died[1/]	Missing	Parasitized	Successful	Mortality[1/]	Parasitized
							----------Pct.----------		
S. festaliella (leaf skeletonizer)	4813	1339	823	485	31	8	61.46	36.22	0.60
C. zimmermani (leaf roller)	3554	1746	1057	711	0	3	60.54	40.72	0.17
P. morio (sawfly)	93	29	11	18	0	0	37.93	62.07	0
A. emigratella	762	353	164	158	31	2	46.46	44.76	0.57
Scotorythra sp.	46	42	7	32	3	0	16.67	76.19	0
Lepidoptera (Unknown)	72	40	25	13	2	1	62.50	32.50	2.50

[1/] These figures may include laboratory induced mortality, but we suspect a good majority of the larvae when brought in from the field were diseased.

mortality may be laboratory induced, we suspect that most larvae were already infected when brought in from the field. Therefore, diseases may be having an unknown suppression potential on the introduced Rubus insects. Although we have not identified nor determined the actual mortality figures attributed to diseases in the field, we suspect a virus and a fungus to be greatly affecting populations of P. morio and S. festaliella, respectively.

DISCUSSION

Our study showed year-round presence and wide distribution of S. festaliella and C. zimmermani which indicate substantial populations on Hawai'i, Maui, and Kaua'i. Based on our observations of feeding damage and overall lack of vigor of most blackberry patches examined, we felt that the original biological control program for R. argutus may have been more successful than presently realized. Perhaps, more credit should be given to S. festaliella and C. zimmermani for reducing the aggressiveness and rapid spread of this weed. With the wild blackberry under some control, priorities might be shifted to other, more aggressive species of Rubus.

During the course of evaluating the status of insects introduced as biological control agents for R. argutus, the need for further studies became apparent with new discoveries. In order to understand the full impact the Rubus insects have on blackberry, additional studies are needed of predators and parasites attacking eggs and early stages of the introduced Rubus insects. Biological information on endemic insects utilizing R. argutus by directly feeding on the foliage, native parasites preying upon the introduced Rubus insects, and disease-induced mortalities on wild populations will greatly enhance the knowledge of R. argutus in Hawai'i.

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